XUV, EUV and Soft-X-Ray Solutions with Compact Laboratory Sources

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Introduction

The Photon Instrumentation group at RI is developing and producing sources and tools for metrology in the spectral range of 1 -50 nm (XUV) for both synchrotron beamline and laboratory use in close cooperation with our research partners.

Our approaches is analyzing user requirements in EUV, XUV and soft x-ray metrology and suggest the most suitable and simultaneously most economic solution for fulfilling the top-level specifications best.

Our application labs with plenty of test sources, we straight forward accomplish proof of concept experiments, which become basis for customer and task specific designs based on our engineering power of sub-units, components and tools. Such solutions are build, tested and delivered and may be turn-key installed at customer sites.

When developing and building our fully autarkic stand-alone laboratory tools we are relying on our broad scope of laboratory XUV-sources of which we know how to tailor towards desired working wavelength, spectral distribution, brightness or power for most efficiently meeting user demands in EUV, XUV and soft x-ray metrology. Starting from experienced design concepts and sub-unit options, we integrate the components XUV-source, sample stages, optics (lenses, mirrors, gratings, and filters) and detectors as to realize the most suitable and simultaneously most economic solution for fulfilling the top-level specifications best. Hence, dedicated variants for specific tasks are easily tailored and may be extremely compact and economic.

History and Network

Our EUV, XUV and soft-x-ray activities are based on activities since 1985 in x-ray lithography, x-ray microscopy, EUV LPP and DPP source developments for metrology and scanner integration and XUV R&D targeting nanolithography, nanoscopy, nanoanalytics, scatterometry, spectrophotometry, thin films, actinic multilayer defects etc. in different institutes and companies over the years (Originating from former ACCEL, RWTH-LLT, FhG-ILT, AIXUV , Philips-EUV, Xtreme Technologies, and Bruker ASC now continued at RI, RWTH-TOS and FhG-ILT activities) .

Institutions involved over the years in our activities

Our Portfolio and Scope of Supplies

We offer and supply:

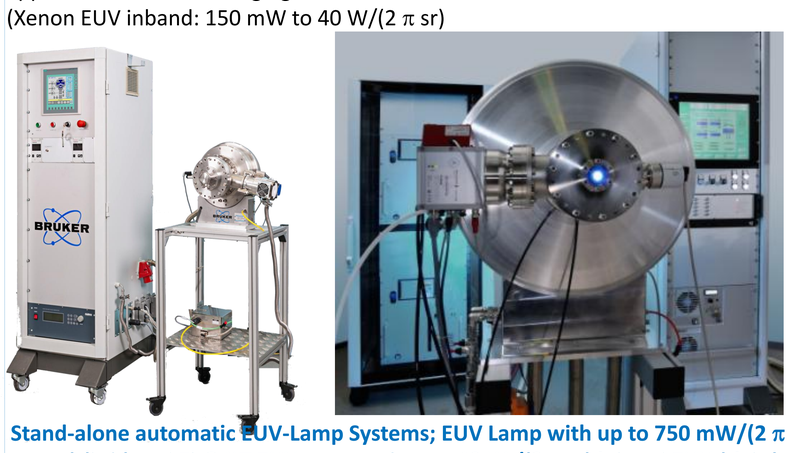
- Tailored LPP and DPP sources for EUV XUV and soft-x-rays
- Components and autarkic tool solutions for metrology and irradiation
- Feasibility and concept studies for effective lab solutions
- Proof of concept and feasibility experiments in our application labs
- Customer specific design, realization and at site installation of tailored sources, specific components and integrated tool solutions
- Measurements and joint experiments at our installations
- Operator and service training.

EUV, XUV and Soft X-Ray DPP Sources

With our laboratory stand-alone DPP XUV-sources such systems are fully autarkic and can be build for different spectral ranges, e.g. soft x-ray (2-5 nm: 250-600 eV), EUV (10-20 nm: 60 – 125 eV) and VUV (20-50 nm: 25-60 eV).

With currents of some kA discharged a plasma of > 30 eV is generated in the spark, such that the working gas emits a spectrum of highly ionized atoms. Hence, the selection of the working gas allows for tuning the spectral distribution; e.g. narrowband line emitters and broadband emission can be generated with the same EV lamp system by just using another working gas.

We have a broad scope of sources and – often very important – source application interfaces ranging from 1 W to > 400 W of total EUV into 2 π sr (Xenon EUV inband: 150 mW to 40 W/(2 π sr)



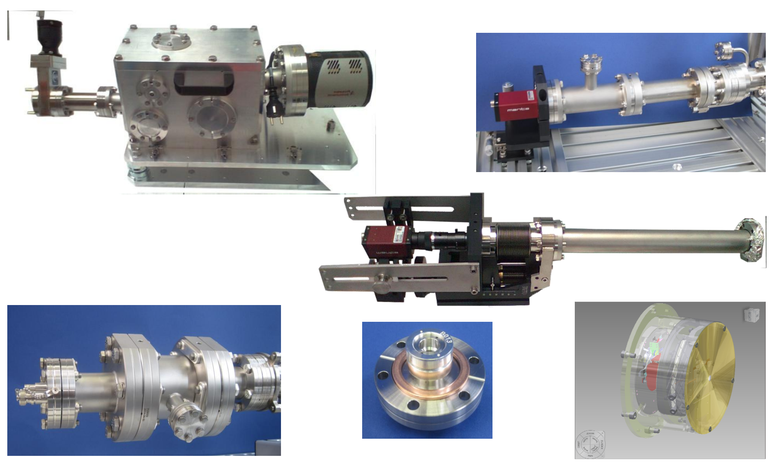
Stand-alone automatic EUV-Lamp Systems; EUV Lamp with up to 750 mW/(2 π sr) (left) and FhG-ILT EUV source of up to 40 W /(2 π sr) inband EUV (right)

The basic DPP concept is supplied by BASC in various configurations. Our standard product for metrology is the EUV-Lamp operated with Xenon, which may be supplemented with OEM or customer specific interfaces or features.

The typical EUV-Lamp with > 150 – 750 mW/(2 π sr) of inband EUV (2- 8 W/(2 π sr) of total EUV). About 500 Mpulses of electrode life (= 2*MTBF) supports 3 months to one year of 8 hour per day emission.

Source Metrology

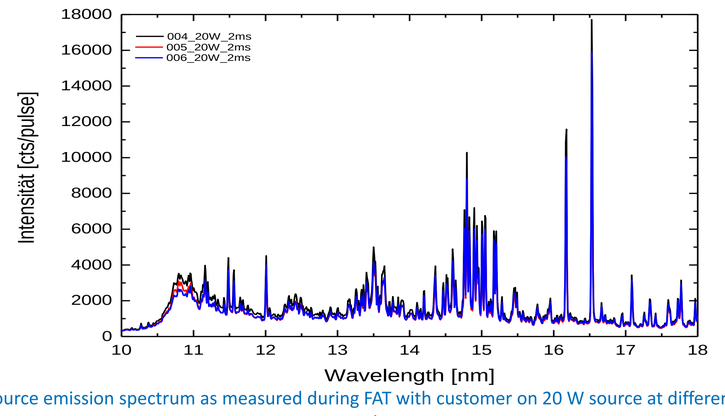
A pre-requisite for effective source developments are tools, which characterizes the emission characteristics. We have realized a set of tools for measuring the EUV emission spectra (E-SPEC), the inband yield (E-MON), the spatial distribution of the inband emission (E-CAM), the temporal emission duration (E-Diode) and other components for actinic beam characterization.



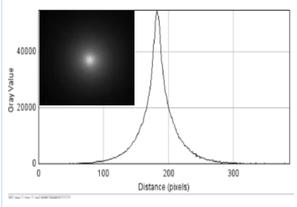
Some tools for actinic source and beam characterization: E-SPEC, S-CAM, Focus monitor, E-MON, E-Diode and irradiation monitor (from top left)

Source Characterization

The following results show some examples of source characterizations demonstrating also source performance.



Source emission spectrum as measured during FAT with customer on 20 W source at different source operation parameters



2b.) **20W** COG-Mask : 5%

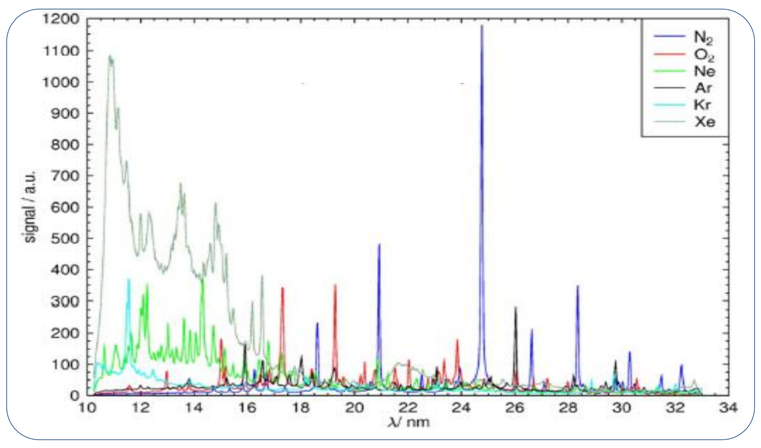
	h. COG [micron]	v. COG [micron]	h. FWHM [micron]	v. FWHM [micron]
Min	2225	2086	270	270
Max	2238	2099	328	328
P-V	13.0	12.4	58.6	58.6
Std. Dev σ	2.4	2.2	11.8	12.0
3σ	7	7	35	36

EUV Source inband emission image and profile at 20 W operation. 200 images statistics show spatial stability of 7 µm (3 σ) and FWHM in the range of 300 µm (35 µm 3 σ)

Source Tailoring

In general, the source can be set-up for the target spectral range. e.g. generating water window photons with photon energies in the range of 500 ev require higher laser intensities or discharge power (currents) than for EUV (around 90 eV). Another option for tuning sources is with the emitting element.

In general, if a source is set-up for a given spectral range any element used in this source will emit its specific spectrum; in general light elements emit line radiation, high-Z elements emit continuous radiation.



Spectral Variability of EUV-Lamp emission when operated with different gases.

Application Specific Source Selection

For the special application source selection has to be performed under various aspects: Demanded power, intensity and spot distribution on the target, economic path for realizing an optical scheme (collimated beam or beam forming collector) and the Required spectral distribution, which is the spectral band of interest (e.g. around 13.5 nm (EUV) or around 12.4 nm (Si-edge) or 4 nm (carbon physics) e.g. and the spectral distribution (line emitter or broadband emitter) for microscopic applications spectral brightness may be important.

In this parameter space DPP and LPP offer specific advantageous : in general it is easier and more cost efficient to deliver high flux with DPP while LPP are advantageous, when high brightness is required (e.g. microscopy).

On the other hand it is more straight forward for each of the source types to work with solids (LPP) or gases (DPP).

In the following we show some tools or applications realized with our sources and concepts.

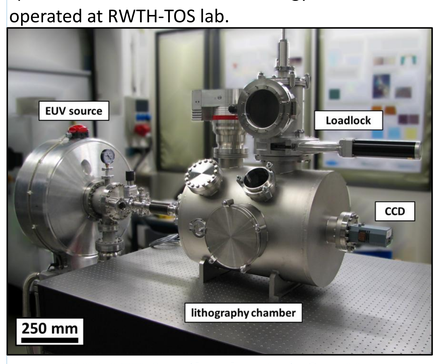
EUV Mask (blank) Reflectometer

With the EUV mask blank reflectometer (EUV-MBR), we developed a high end tool for the industrial lab exhibiting 1.6 pm spectral channel resolution and fully automatic recipe based processing. By using our EUV-Lamp we have maintenance intervals and MTBFs in the range of some 1000 samples or 10.000 spots and low cost of ownership.

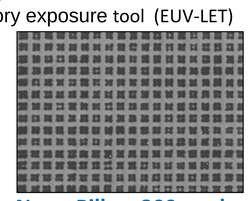
Actinic stand alone EUV Mask (Blank) Reflectometer with integrated EUV-Lamp

EUV Resist and Material Exposure

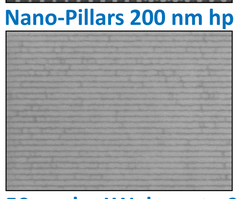
Over the time, we have realized various tools for EUV resist and material irradiation resp. exposure experiments. Achieved features are high accuracies for determination of resist sensitivity (TEUVL), High dose > 10 mJ/mm² per pulse and power > 2 W/cm² irradiation. Of special relevance for nanotechnology is the EUV laboratory exposure tool (EUV-LET) operated at RWTH-TOS lab.



EUV-LET Application Lab Set-Up



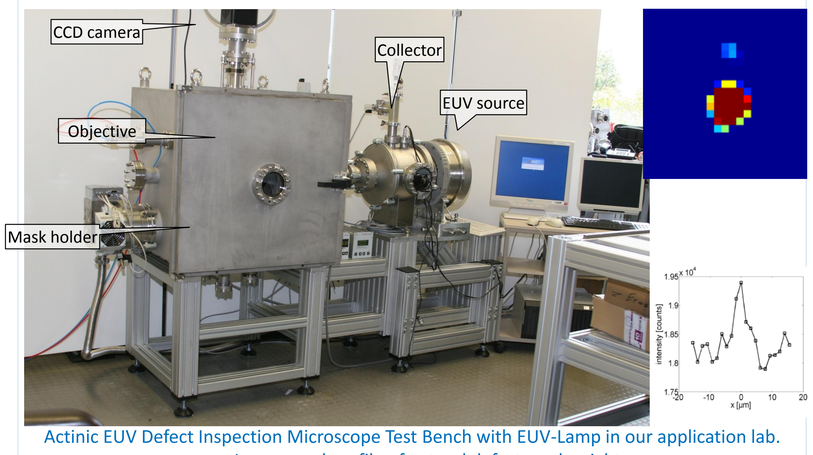
Nano-Pillars 200 nm hp



L/S: 50 nm hp LW down to 9 nm

Actinic Blank Inspection Microscope Test bench

Actinic blank inspection (ABIT) is still an open keystone of EUVL infrastructure. As discussed such tools are required with high throughput at least at all mask suppliers. As reported we have demonstrated a R&D test bench targeting sensitivity to buried defects of less than 30 nm.

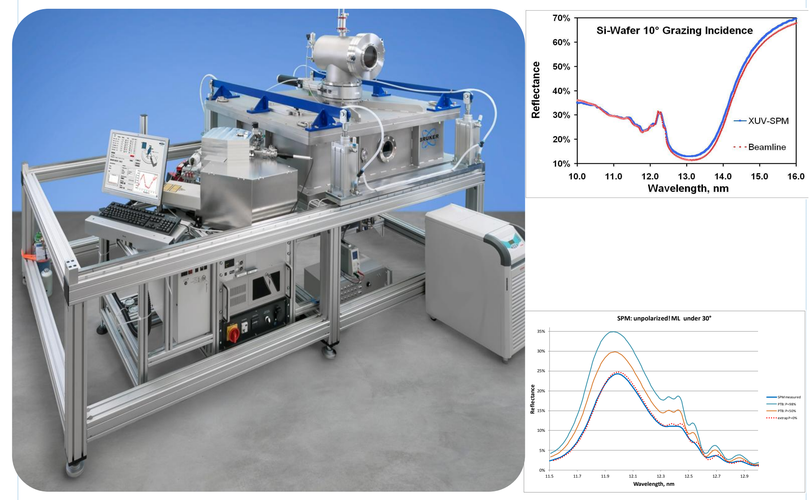


Actinic EUV Defect Inspection Microscope Test Bench with EUV-Lamp in our application lab. Images and profile of natural defect on the right,

XUV Spectrophotometer

For spectroscopic investigations, only little flux is required. On the other hand, broadband homogeneous spectral emission distribution eases the task. Hence, for the XUV-spectrophotometer an LPP of < 1 mW/sr broadband power is sufficient to obtain good results on (50 µm)² spots on sample reflection or transmission within less than one minute of exposure.

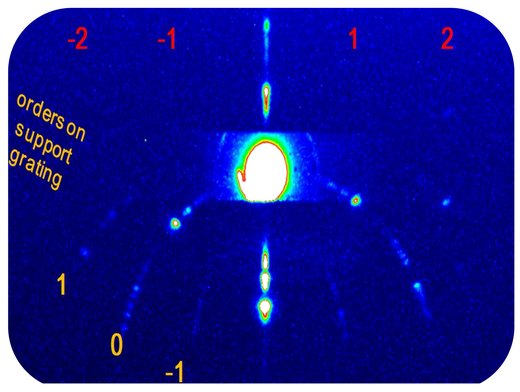
Gold emission delivers coverage of spectral ranges from 2 to > 50 nm when required. For similar task in EUV mask metrology, broadband DPP xenon emission is well suited – although of much higher flux (> 500 x).



XUV Spectrophotometer with LPP source and two typical results in GI and NI.

CD Scatterometry

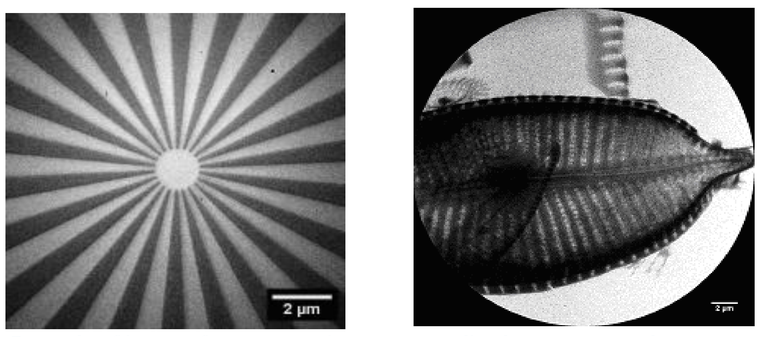
CD Scatterometry for sub 20 nm structures required line emitters, which are strongly collimated. With the spectral variability of the EUV-lamp, we get line emission of Argon, Neon or Nitrogen in the desired spectral ranges. Collimating of the source with a 50 µm diameter pinhole in 1 m from the DPP EUV-Lamp has been used to obtain c decent CD-signatures within 1 second of exposure



CD-WA-XUV-S results from 50 nm L/S structures.

Nanoscopy

Nanoscopy in general is the most demanding with respect to brightness of a source. Such EUV-a—pattern microscopy requires in the range of (100 W/mm² sr) . When nanoscopy is performed in “water-window”- with Fresnel zone-plates, Even higher brightness ate required within one single emission line. Good results with “X-ray microscopes have been realized with LPP and DPP source developments from our research partners using nitrogen line emission. >



Example of images from x-ray microscope realized at our research partner Fraunhofer-ILT..

Summary and Outlook

With a broad portfolio of (DPP and LPP) sources we can cover a wide range of parameters and such select and tune for most efficient and cost effective solution for many applications in the field of EUVL and general nanotechnology and develop solution in our application labs.

We are positioned to supply power levels from mW/sr to 100s of W/sr, source sizes from 20 – 1000 µm diameter, brightness up to some 100 W/(mm² sr) and spectral distribution matched to sub-ranges of 2 - 50 nm with either line or continuum spectral characteristics.

Supported by the German country of NRW and the recently started European Cooperation in **IKT 2020-Ecsel:** Seven Nanometer Technology: SeNaTe (we are using and intensifying our developments and application labs for nanoanalytic tools and EUV mask, mask blank and pellicle metrology and material and resist irradiation tests.

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